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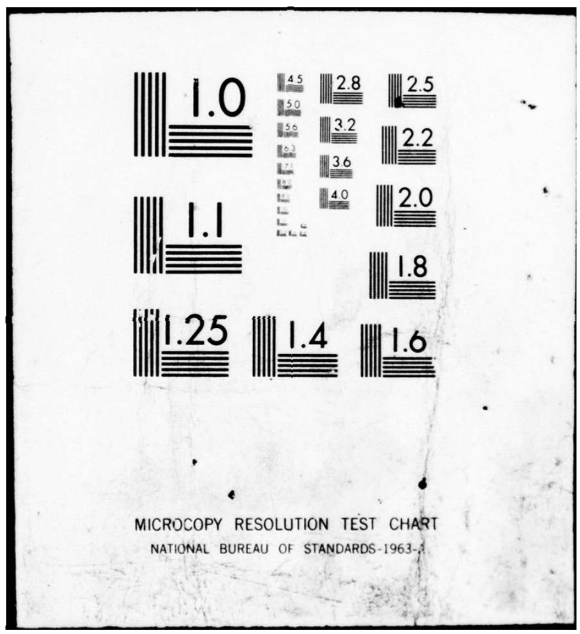
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PROGRESS TOWARD THE CROSSTIE MEMORY VI

BY L. J. SCHWEE W. E. ANDERSON Y. J. LIU
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RESEARCH AND TECHNOLOGY DEPARTMENT

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) NSWC/TR-79-97 (WOL)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) Progress Toward the Crosstie Memory ~~VI~~.		5. TYPE OF REPORT & PERIOD COVERED 6th Annual Report, no. 6 October 1977-30 September 1978
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) L. J. Schwee, W. E. Anderson, Y. J. Liu, Oscar Van Sant, Emma Lee Hebb		8. CONTRACT OR GRANT NUMBER(s) (16) (17)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Surface Weapons Center White Oak Silver Spring, Maryland 20910		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62762N; F54545; WF54545602 CR34BA
11. CONTROLLING OFFICE NAME AND ADDRESS (12) 32p. (11)		12. REPORT DATE 12 March 1979
		13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Memory	Neel Wall
Thin Film Memory	Magnetic Memory
Crosstie Memory	Shift Register
Crosstie Wall	Magnetic Shift Register

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is the sixth annual technical report of progress toward the crosstie memory and it emphasizes work done during the past year. The five previous reports can be obtained upon request of the authors.

Progress has proceeded to the point where shift registers can be demonstrated under observation with Bitter solution. The complete demonstration using Bitter solution was done at Sperry Univac, St. Paul, MN. Propagation experiments at NSWC were successful along the entire length of the shift register except where the bit enters the detector. Efforts being made to → next page

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optimize operation are detailed in this report.

With the use of Bitter solution a 12 megabit/sec shift rate was demonstrated. Detection at a 1 megabit/sec rate has been demonstrated at Univac. The next step is to demonstrate data in and data out at a high rate.

SUMMARY

The purpose of this report is twofold. First, it is intended to serve as an annual report to the Naval Air Systems Command. Second, it is intended to summarize in one place our present knowledge, techniques, and opinions concerning the Crosstie Memory. There are also available several papers referenced in this and previous reports which have been presented at the Intermag Conferences and Conferences on Magnetism and Magnetic Materials. These papers can be found in the IEEE Transactions on Magnetics, the AIP Conference Proceedings, and the Journal of Applied Physics.

The work reported here was funded by NAVAIR Task No. WF54545602.

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Chapter I

INTRODUCTION

Crosstie Memory development has progressed to the point where experimental shift registers have been demonstrated by Sperry Univac in St. Paul, Minnesota.[1] Minor differences exist between the propagation scheme used by Univac and the one used in our laboratory. There are several alternative ways of propagating, detecting, and organizing the memory. Now that we know that the memory will work, we can concentrate on making it work well.

This report details the propagation experiments which were performed during the past year. It also explains some experiments which are underway to make the memory more reliable and easier to test.

1. D. S. Lo, V. M. Benrud, G. J. Cosimini, L. H. Johnson, G. F. Nelson, M. C. Paul, and E. J. Torok "Crosstie Shift Register," J. Appl. Phys., March 79.

Chapter II

PROPAGATION

The thin film circuit used for propagation is shown in Figure 1. Here holes were placed in the middle of the wide conductor portions of the narrow-wide line to spread the current away from the wall which runs down the center of the serrated strips. The holes allowed us to observe crossties and Bloch lines using a Bitter solution. The tips of the crossties could be seen in the narrow sections. Video tapes were made of some propagation experiments and may be borrowed by writing to the authors of this report. The narrow-wide line is used to provide weak or strong fields on every other serration. An additional field not shown in Fig. 1 was provided by a small coil behind the substrate. It is better to provide the additional field by a stripline insulated from and buried below each serrated strip. But for the purpose of these experiments, a coil was used to save fabrication steps.

There are three fields to be concerned with in propagation as have been discussed previously.[2,3] The first of these fields, H_s, is fixed by the dimensions of the serrated strip. In our case the strip was 15 μm wide at the narrowest points, with serrations 8 μm in length. The field H_s can be approximated by

$$H_s = A \sin(2\pi x/\ell) \text{ Oe} \tag{1}$$

where ℓ is the distance along the strip starting at a narrow point along the serration. The value of A for the serrations shown in Figure 1 is -2.6 Oe.

Another field is that produced by the coil previously mentioned. This field is constant as a function of distance along the strip and can be written as

$$H_c = C. \tag{2}$$

The third field to be concerned with is that produced by the narrow-wide conductor. This field has a period twice that of the serrated strip and can be approximated by

$$H_g = B + D \sin(\pi x/\ell + \psi) \tag{3}$$

2. L. J. Schwee, W. E. Anderson, Y. J. Liu, and R. N. Lee NSWC/WOL TR 78-11.
3. L. J. Schwee, W. E. Anderson, Y. J. Liu, and R. N. Lee, "Approaches Toward Field Determined Propagation of Crossties and Bloch Lines" J. Appl. Phys., 49, 886 March 1978.

where the relationship between B and D is fixed by the width of the wide part of the narrow-wide conductor with respect to the narrow part. Also, it is affected by the hole in the wide part if it is used. The phase angle, ψ, is added to equation (3) because the narrow-wide conductor does not necessarily have to be placed as shown in Figure 1. In fact, previously[3] experiments were performed with the serrated strip at a phase angle of $\pi/2$ away from the phase angle shown in Figure 1. Both phase angles were found to be suitable for propagation. It appears that for nearly any value of ψ, propagation can result by properly adjusting constants B, C, and D. For some values of ψ, however, much more power is needed. The optimum value of ψ is being experimentally determined.

A circuit has been constructed in which the phase angle ψ changes by one tenth of the period after every 16 serrations. This circuit will be used to determine the optimum phase angle for propagation.

The drive circuitry which was used for the propagation experiments was built from TTL integrated circuits except for the output stages and four phases were used. On the first phase the Bloch line was moved; on the second phase, the crosstie was moved; on the third phase the Bloch line; and on the fourth phase, the crosstie. The values of current through the narrow-wide conductor and the magnetic fields of the coil are listed below.

	Narrow-wide	Coil
Phase 1	-48 mA	21 Oe
Phase 2	-104 mA	65 Oe
Phase 3	+37 mA	-21 Oe
Phase 4	+96 mA	-27 Oe

The narrow-wide was placed in series with the coil so pulse rise times would be coincident. Resistive shunts in parallel with the narrow-wide conductor provided the current ratio differences in the four phases.

Propagation was successful using the circuit shown in Figure 1, but because of the permalloy left under the gold conductors (gold was electroplated onto the permalloy), propagation into the detector was found to be impossible. Meanwhile, a similar circuit was fabricated at Univac using vapor deposition of gold[1], and there the complete shift register was shown to work. The shift register operation was done by observing crossties with a Bitter solution and observing a detector signal as the bit entered the detector. The next step is to demonstrate data in and data out at a high rate.

Chapter III

BIT DENSITY

Most of the experimental shift registers being tested at this time are large compared to what is possible using crossties. The serrations shown in Figure 1 are 15 μm at the narrow points across the tracks and each serration is 8 μm along the track. The natural spacing of crossties in permalloy with a 4 Oe anisotropy field is about 5 μm apart. If the anisotropy is increased the spacing becomes about 2 μm apart at 7 Oe. The density therefore is strongly dependent on film anisotropy.

When serrated strips are used, the anisotropy of the film is replaced by shape anisotropy which becomes very strong near the edges of the serrated strips. Therefore, if the serrated strips are made narrower, the shape anisotropy fields increase and smaller and smaller crossties can be obtained. It appears that crossties can be obtained in sizes approaching a micron provided the serrated strips can be formed that small. Using conventional photolithography the density will be limited to about 10^7 bits/in^2.

Chapter IV

GEOMETRICALLY DEFINED TRACKS

In last year's report[2] the crosstie wall was shown to be held by a step in the substrate. It was thought at that time that the local easy axis perpendicular to the step was being caused by yield in the magnetostrictive film at the step. There is another explanation for this behavior. When a step in the substrate is made, an angle of incidence with respect to the source material used in evaporation exists at the edge of the step. Such an angle of incidence gives rise to large anisotropies measured in hundreds of oersteds[4] as shown in Figure 2. The sign of the anisotropy changes from positive to negative at about 70°. The films which have been used have been sputter etched with angles near 90°. If the substrate is chemically etched, an angle close to 45° usually results. Experiments are being done to confirm this angle of incidence effect as the cause of such behavior.

Without such a step, a field of a few tenths of an oersted can move the wall in the serrated strip away from the center of the strip. With a step present, a field of about 3 Oe was needed to move the wall off the step.[5] The step then is considered an important improvement in case shielding the memory from external magnetic fields is a problem.

There is another effect which should be mentioned in connection with oblique incidence permalloy films. If a step is chemically etched so the angle of incidence is about 45°, and the film is deposited at 200°C, and then vacuum annealed at 300°C, the easy axis will rotate by 90° if the magnetostriction is negative.[6]

Characterization of steps on substrates is being pursued so we can find the best conditions for holding crosstie walls in the center of the serrated strips.

4. M. S. Cohen, "Anisotropy in Permalloy Films Evaporated at Grazing Incidence," J. Appl. Phys. 32, Supplement p. 87s March 1961.
5. Y. J. Liu, L. J. Schwee, and W. E. Anderson, "Crossties and Spikes on Geometrically Defined Tracks," IEEE Trans. Magn. Vol MAG-14 p. 886 Sept. 1978.
6. G. P. Weiss and D. O. Smith, "Annealing of Oblique Incidence Permalloy Films," J. Appl. Phys. 32, Supplement, 85s, March 1961.

Chapter V

THE KERR EFFECT

An attempt was made to observe walls in serrated strips using the Kerr effect. This had been done on continuous films previously.[7] The problem with serrated strips in such an observation is the light which returns where the permalloy is absent. A very intense light source must be used and polarizers must be crossed close to extinction. When conditions are right for near extinction in the areas where the permalloy is present, the conditions are wrong where it is absent. The intense light is blinding and subtle changes in intensity are not observable with the human eye. To get around this problem, the permalloy was not etched as usual to form the serrated strips. Instead, an electroless gold deposition technique was used which substituted gold for the permalloy in the areas unprotected by photoresist. This process was timed carefully so all the permalloy was replaced by gold except for about 5 or 10 Å. Otherwise the gold would not stick to the substrate.

The gold absorbed much of the light and enabled us to view the positive and negative Neel walls in the serrated strips. We were able to use 200x magnification and view the phenomenon on a closed circuit TV monitor using a conventional vidicon. Much better contrast can be obtained using silicon intensified low light level cameras. If higher magnifications can be used with low light level cameras, the high intensity light can be blocked out by placing some black paper with a slit in it between the objective lens and the vidicon. Viewing the shift registers magneto-optically can be a great help in testing. The preferred method of observation was discussed previously.[8]

---

7. L. J. Schwee, H. R. Irons, and W. E. Anderson "Propagation and Observation of Digital Information Stored in the Crosstie Memory," IEEE Trans. on Magn. MAG-10 p. 564 Sept. 1974.
8. L. J. Schwee, H. R. Irons, A. D. Krall, W. E. Anderson, J. K. Watson, NOLTR 73-185.

Chapter VI

TEST ELECTRONICS

The output stages of the drive circuitry used in the propagation experiments are shown in Figure 3. At the top of the figure are shown the numbered leads which correspond to the four phases described in Chapter II. This circuit was designed for use with a coil instead of a stripline and consequently it is designed to handle currents up to an ampere. When a stripline is used, lower power transistors can be used, and the emitter follower transistors (2N3725) can be eliminated. When lead number one is taken high, the emitter of the corresponding 2N3725 goes high and turns on the two 2N4923 transistors to which it is connected. All other transistors are open. The current path is then through the two conducting 2N4923 transistors, the narrow-wide conductor and the coil and the resistor in parallel with the narrow-wide conductor. This arrangement is a bit awkward because the coil and narrow-wide conductor potentiometers interact, but it is necessary because of coil inductance. If a stripline is used, it should be possible to place the stripline in parallel with the narrow-wide conductor so the amplitude controls do not interact. The ten volt supply was used because of resistances in the long leads connected to the narrow-wide conductor.

The sequence used for propagation was to put a pulse into conductor #1, then #2, then #3, then #4, then #1 and so on. A four bit serial-parallel shift register connected as a ring-counter was used to do this. In addition, when the shift register was stopped on phase #3 for example, a pulse train continued to flow to lead number three of Figure 3. This allowed us to turn the appropriate two potentiometers until the desired effect occurred (in this case it is Bloch line push).

The circuit was designed so resistors could easily be changed when different circuits were tested. Those resistors in the diagram marked with a zero correspond to resistor holders with a piece of wire shorting them out.

Generation circuitry was also built but it is not included on the diagram shown in Figure 3.

The next step is to test at high data rates without using the Bitter solution.[9] We know that the drive fields may drop by as much as 75% without the Bitter solution. The magnetooptic effect can be a great help in setting up the proper drive fields for future testing. Pure electronic testing with data in and data out at high rates appears possible but must be approached cautiously, knowing that the drive fields may differ greatly from those measured with Bitter solution.

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9. G. Cosimini and J. H. Judy, "Crosstie Dynamic Nucleation Thresholds and Bloch Line Mobility Measurements in Thin Permalloy Films," Joint MMM-Intermag Conference, Pittsburgh, 1976.

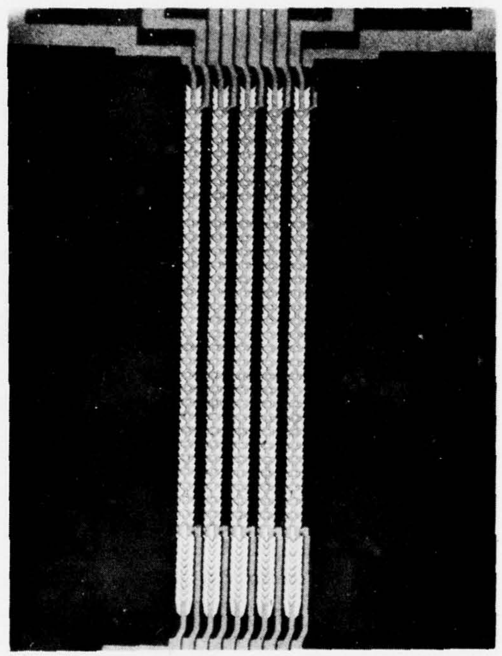

FIGURE 1 PHOTO OF THIN FILM CIRCUIT USED FOR PROPAGATION EXPERIMENTS

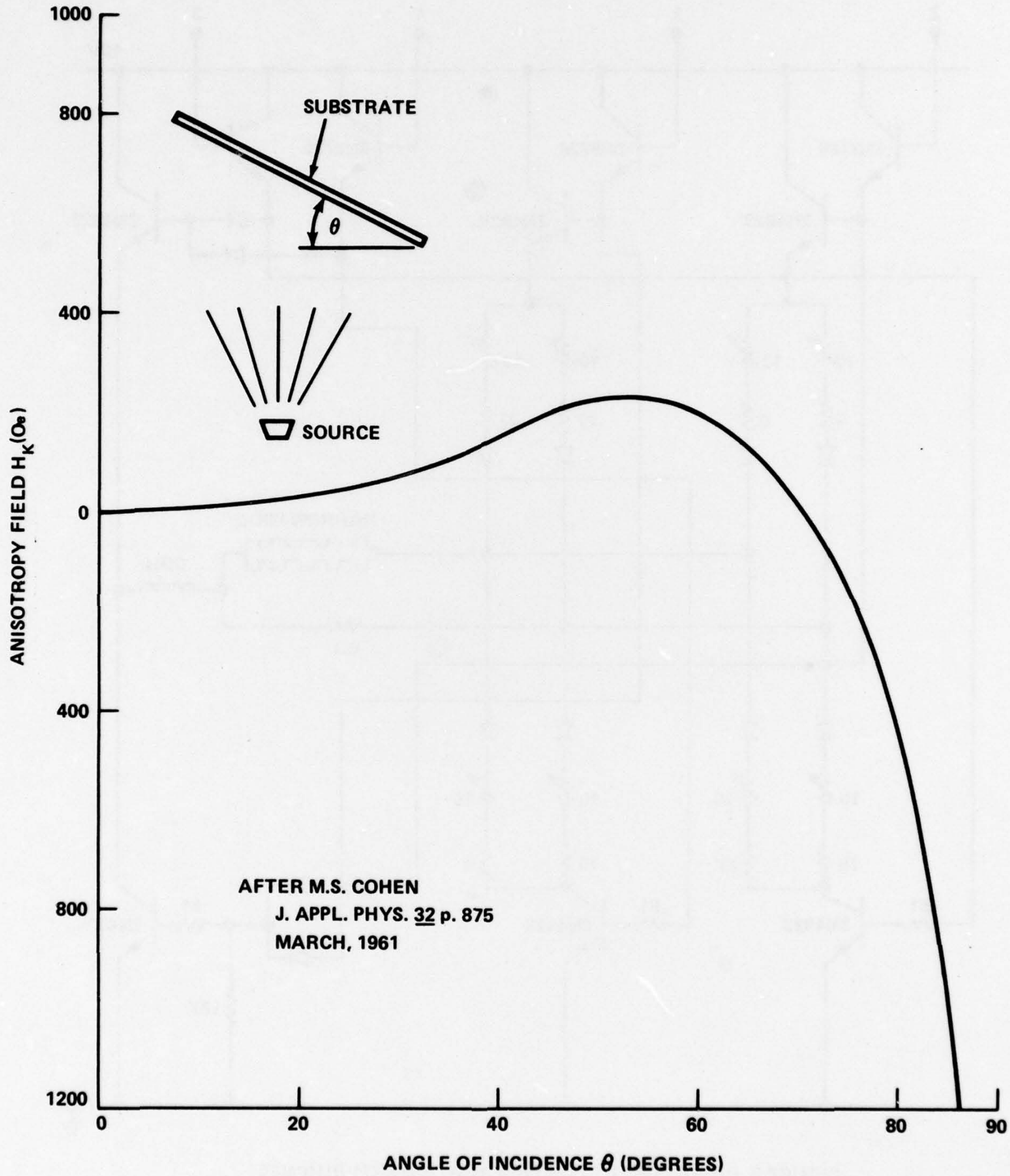

FIGURE 2 ANISOTROPY FIELDS DUE TO DEPOSITION AT OBLIQUE INCIDENCE

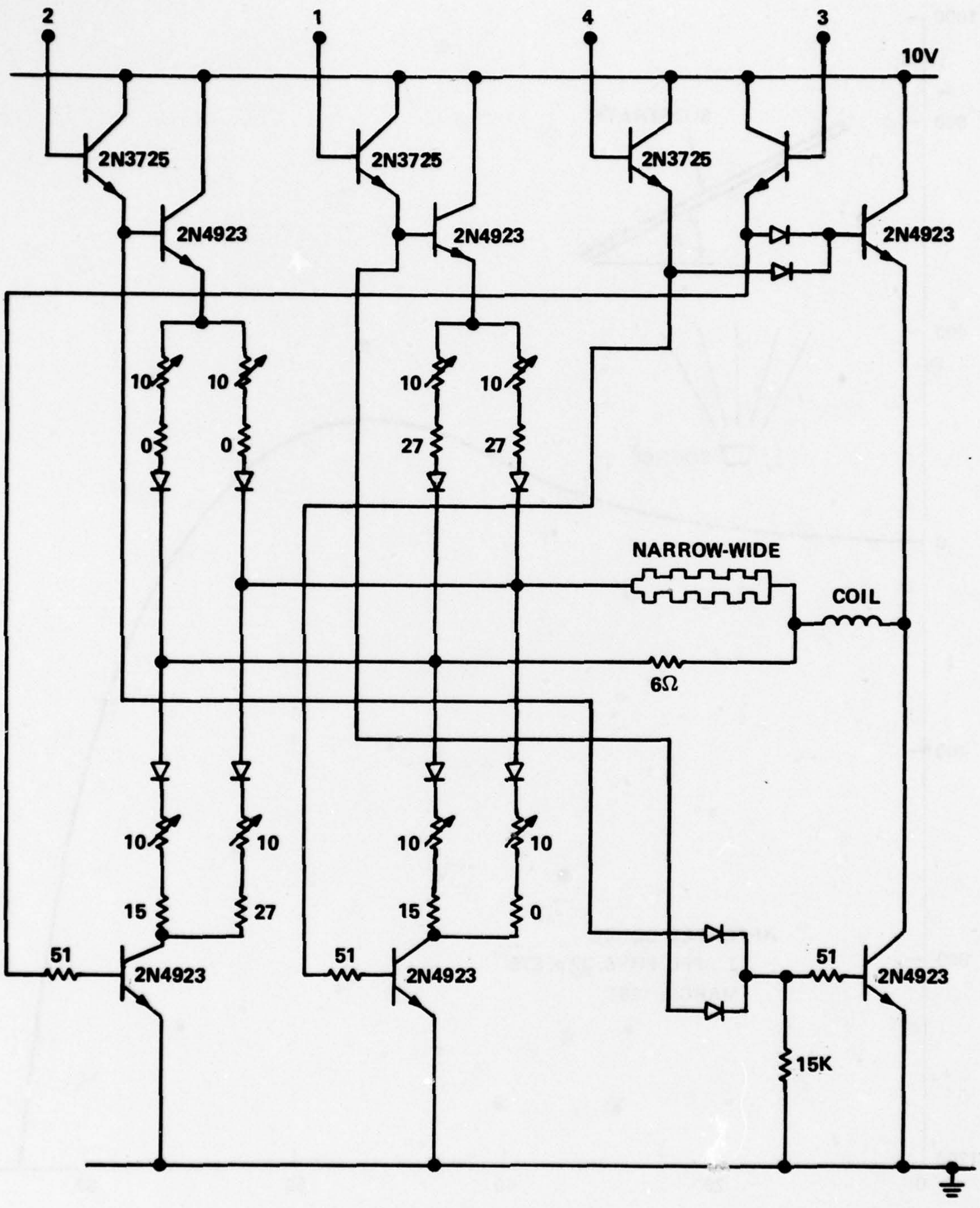

FIGURE 3 DRIVE CIRCUIT FOR PROPAGATION EXPERIMENTS

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